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THALLIUM MERCURY LASER DEVELOPMENT

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C. S. Liu and D. W. Feldman

FINAL REPORT (PHASE III)

(Period between Feb. 1, 1980 and Jan. 31, 1981)

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THALLIUM MERCURY LASER DEVELOPMENT

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1. INTRODUCTION AND SUMMARY

This report summarizes research work performed at the Westinghouse R&D Center under ONR Contract No. N00014-78-C-0131 for the period between Feb. 1, 1980 and Jan. 31, 1981. The major effort was to investigate the feasibility of generating ultra-short laser pulses (<5 ns) from a CuBr laser for Navy bathymetry applications.

Technical requirements for the bathymetry laser are:

- Wavelength: 500 to 550 nm primary, with desired 550 to 600 nm secondary line.
- Pulse Width and Shape: 2 ns desired, 5 ns maximum with rise and fall times less than 2 ns.
- Peak Power: 75 kW peak desired, 20 kW minimum.
- Pulse Repetition Rate: 13 kHz desired; 3 kHz minimum.
- Weight and Prime Power: Weight less than 100 lb, laser volume 2 to 3 ft^3, prime power less than 1 kW.

In addition, the bathymetry laser must be suitable for fabrication of a subsequent operational version which can be utilized in an airborne environment. Thus the desired characteristics of ruggedness, reliability, maintainability, operator safety, low electrical interference, and long lifetime are implied for this laser.

An evaluation of current laser technology reveals that no laser devices are presently available which satisfy these requirement simultaneously. However, virtually all of the key technical features have been realized separately, and some laser technologies have already

demonstrated simultaneous satisfaction of all but the pulse width and/or prime power requirements. A search of these technologies leads to the conclusion that a single copper halide laser oscillator can satisfy all the technical requirements for the bathymetry applications. Since the round trip photon time of a 0.75 m, laser cavity is 5 ns, short CuBr laser tubes were tested. A laser pulse of $\sim$140 μJ with less than 5 nsec (4.5 nsec) duration, corresponding to a peak power of $\sim$30 kW, operated at $\sim$15 kHz was produced from a long-lived, sealed-off CuBr laser having a longitudinal discharge 2 cm in diameter and 22 cm long. These experimental results have provided sufficient evidence that the short CuBr laser can be used for Navy bathymetry applications.

2. EXPERIMENTS AND RESULTS

Continuously pulsed, high prf CuBr lasers have been operated at several hundred μJ per pulse[1] in self-heated, sealed-off laser tubes with efficiencies of ∿0.8%. However, the laser pulse width were 20 to 50 nsec long. In order to shorten the laser pulse without sacrificing beam quality and laser efficiency significantly, one should increase the laser excitation rate and reduce the cavity length[2] simultaneously. The necessary but not sufficient condition for obtaining a laser pulse of less than 5 ns is that the round trip photon transit time inside the optical cavity must be much less than 5 nsec. These conditions may be achieved through the use of a fast electrical circuitry and a compact resonator structure ($\ell \sim 30$ cm).

As a guide to the design of the laser tube, Table 1 contains some parameters for a bathymetry laser.

Table 1. Design Parameters for a Bathymetry Laser Tube

Laser Medium: CuBr

Temperature: 300°C to 600°C

Volumetric Energy Yield: 2.0 - 5.0 $\mu J/cm^3$

Pulse Repetition Rate: ∿16 KHz

Energy Output Per Pulse: ∿375 μJ @ <5 nsec

Peak Power: ∿75 kW

Discharge Dimensions: 25 cm × 2.0 cm diameter

Efficiency: ⩾.2%

Both transverse and longitudinal discharge excited CuBr laser tubes were investigated. However, because of the difficulty of impedance matching between the laser discharge in the transverse configuration and the existing pulser, most of our experimental effort in this contract period was devoted to longitudinal discharge excited CuBr lasers.

The longitudinal laser tube was fabricated from high quality quartz with molybdenum:quartz cup seals serving as electrical feed-throughs. Optical grade quartz windows were fused onto the discharge tube ends. Electrodes were made of molybdenum cups. In previous experiments this type of laser tube was successfully operated for hundreds of hours without failure under a power loading of 50 W/cm^3.

The resonator consisted of a total reflector and a flat output coupler. The total reflector was a quartz corner cube, whereas the output coupler was simply the flat quartz window fused onto one end of the laser tube. The use of a quartz corner cube reflector enabled us to obtain excellent reflectivity in the visible and to place it very close to the Brewster window (inside the oven) which gave a resonator whose length was only a few centimeters longer than the discharge region (see Figure 1). With a discharge length of 22 cm, the overall resonator was $\sim$30 cm with a photon round trip time of 2 nsec. The alignment of the resonator was automatic because of the retro-reflection properties of a corner cube reflector and thus the axis of the resonator was defined by the normal to the quartz plate coupler. This eliminated the need for mirror gimbals or other alignment mechanisms operating at high temperatures. In principle the corner cube could also be fused to the discharge tube shortening the laser cavity even more and eliminating all external laser cavity optics.

The electrical circuit has been described previously[3] and is a standard Blumlein configuration. To avoid problems of temperature control the laser was operated in a pulse burst mode lasting about 2 msec. In this way the average electrical power dissipated was negligible but the burst lasted sufficiently long to simulate steady state conditions.

The variation of laser output energy with laser tube temperature is illustrated in Figure 2. At 400°C the CuBr vapor density was near threshold at 1.6×10^{15} cm^{-3} and laser emission only at 5106 Å was observed. Peak laser energy was obtained at 525°C where the CuBr density was 7.9×10^{16} cm^{-3}. Under optimum conditions, we obtained a 4.5 nsec wide laser pulse with $\sim$140 μJ/pulse at 0.135% electrical to optical conversion efficiency.

The laser output energy as a function of pulse repetition rate is shown in Figure 3. The CuBr laser lased from 3 kHz to 22 kHz and its optimum prf was at ∿16 kHz. In the low prf regime the yellow laser radiation at 5782 Å was weak, at 16 kHz the ratio of laser radiation at 5106 Å and 5782 Å was 3:1 and at very high prf the laser radiation is predominantly yellow. The laser pulse width was almost independent of the pulse repetition rate and was always approximately 4.5 nsec.

Figure 4 illustrates the variation of laser efficiency at optimal conditions with specific output energy. An efficiency of .4% was attained with specific output energy of less than 0.5 μJ cm^{-3}. The laser efficiency decreased rapidly to ∿.15% as the output energy density was increased to ∿2 μJ cm^{-3}. However, the short pulse of ∿4.5 nsec was only obtained when the output energy density was over 2 μJ cm^{-3}. Operating under high efficiency and low specific output energy mode (<.5 μJ cm^{-3}), and shortening the resonator length has no effect on the laser pulse width. The laser pulse width was about ∿20 nsec which was controlled by the lifetime of the upper and lower laser levels. In order to produce ultra-short CuBr laser pulses, it is necessary to pump the laser harder (>2 μJ/cm^3) as well as to shorten the cavity length. With an output specific energy of 2 J/cm^{-3}, we obtained a laser pulse width of 8.5 nsec with a 60 cm long cavity length and reduced it to 4.5 nsec by decreasing the cavity length to 30 cm. Table 2 list the laser output performance with various parameters.

Table 2

2 cm diameter x 22 cm long

Cavity Length cm	Prf kHz	Specific Energy μJ/cm^{-3}	Pulse Length t	Laser Energy μJ	Efficiency η
30	16	0.5	20 ns	35	.4%
30	16	2.1	4.5 ns	145	.135%
60	16	0.5	25 ns	35	.4%
60	16	2.1	8.5 ns	145	.14%

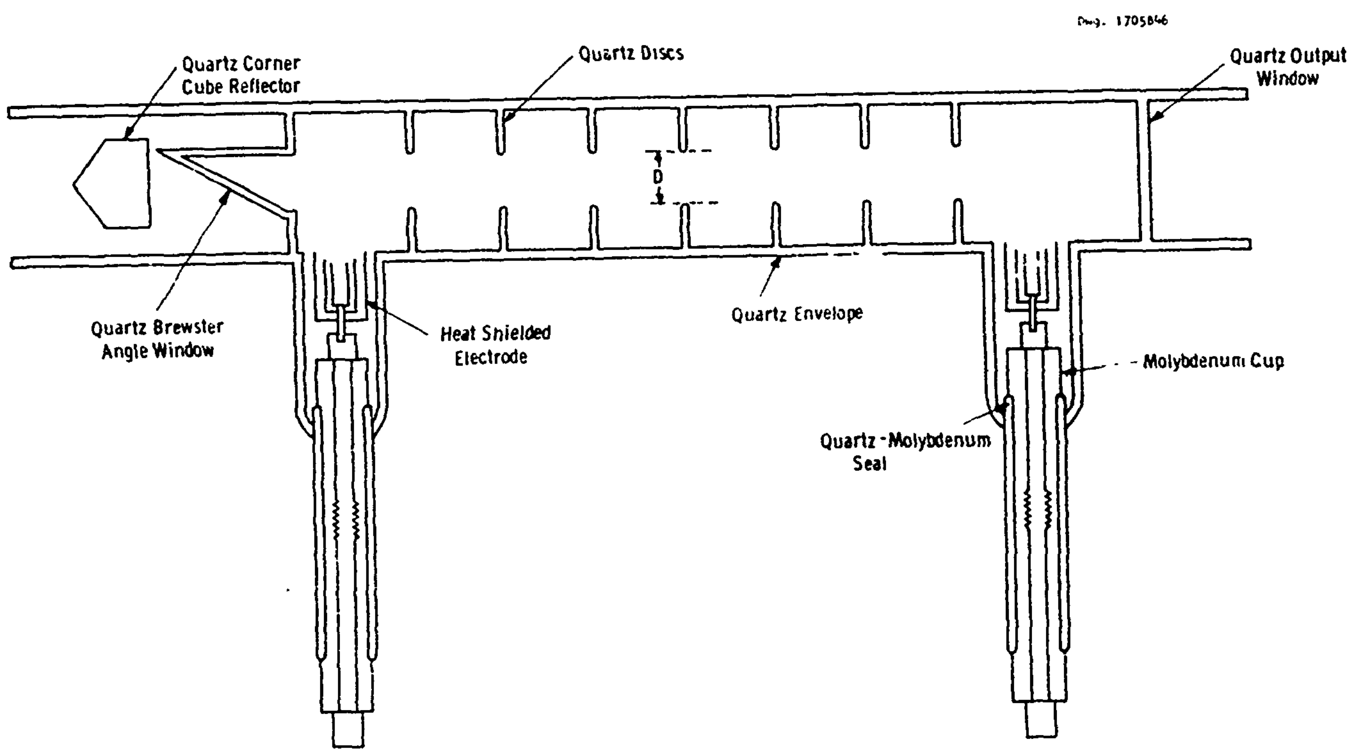

Fig. 1 – Longitudinal discharge tube with sidearm feedthrough

Curve 727433-A

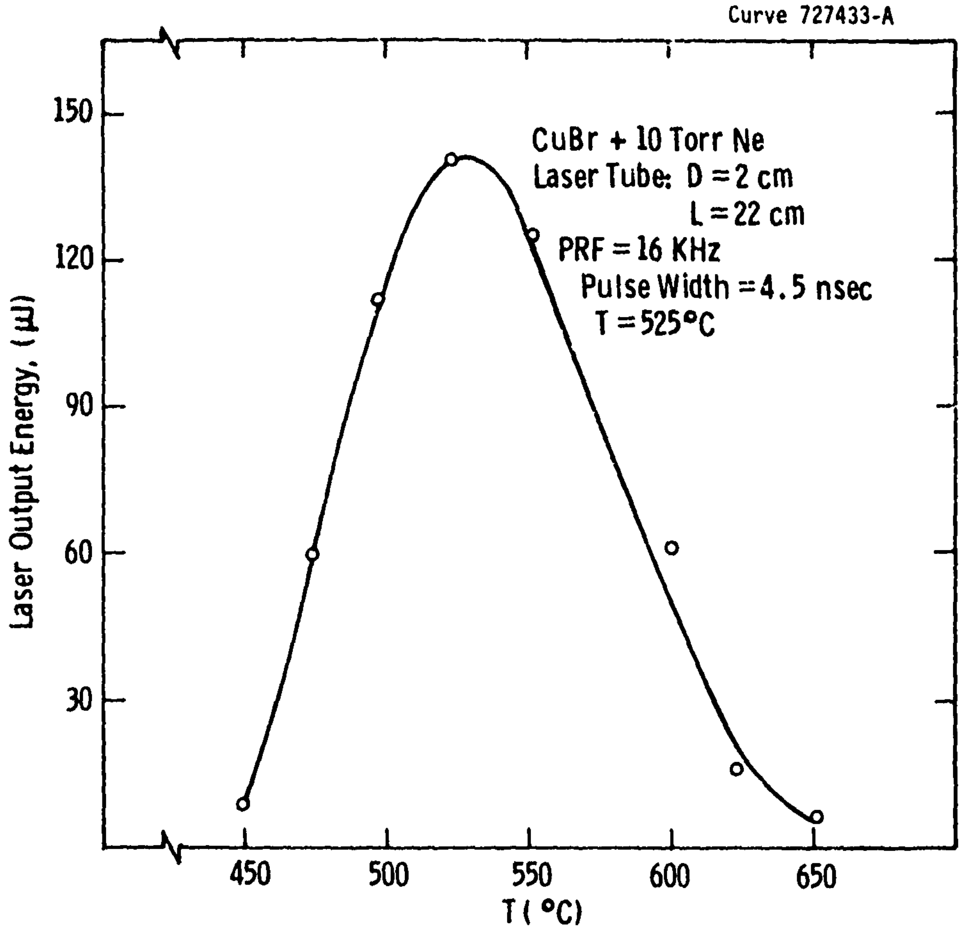

Fig. 2 — Laser output energy as a function of reservoir temperature

Curve 727434-A

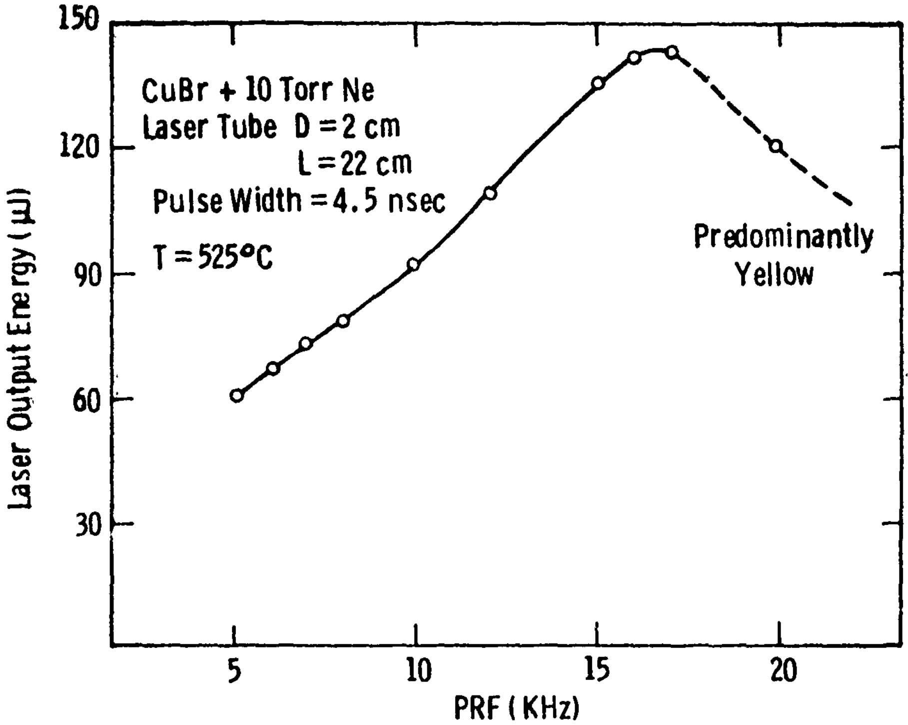

Fig. 3 — Laser output energy as a function of pulse repetition rate

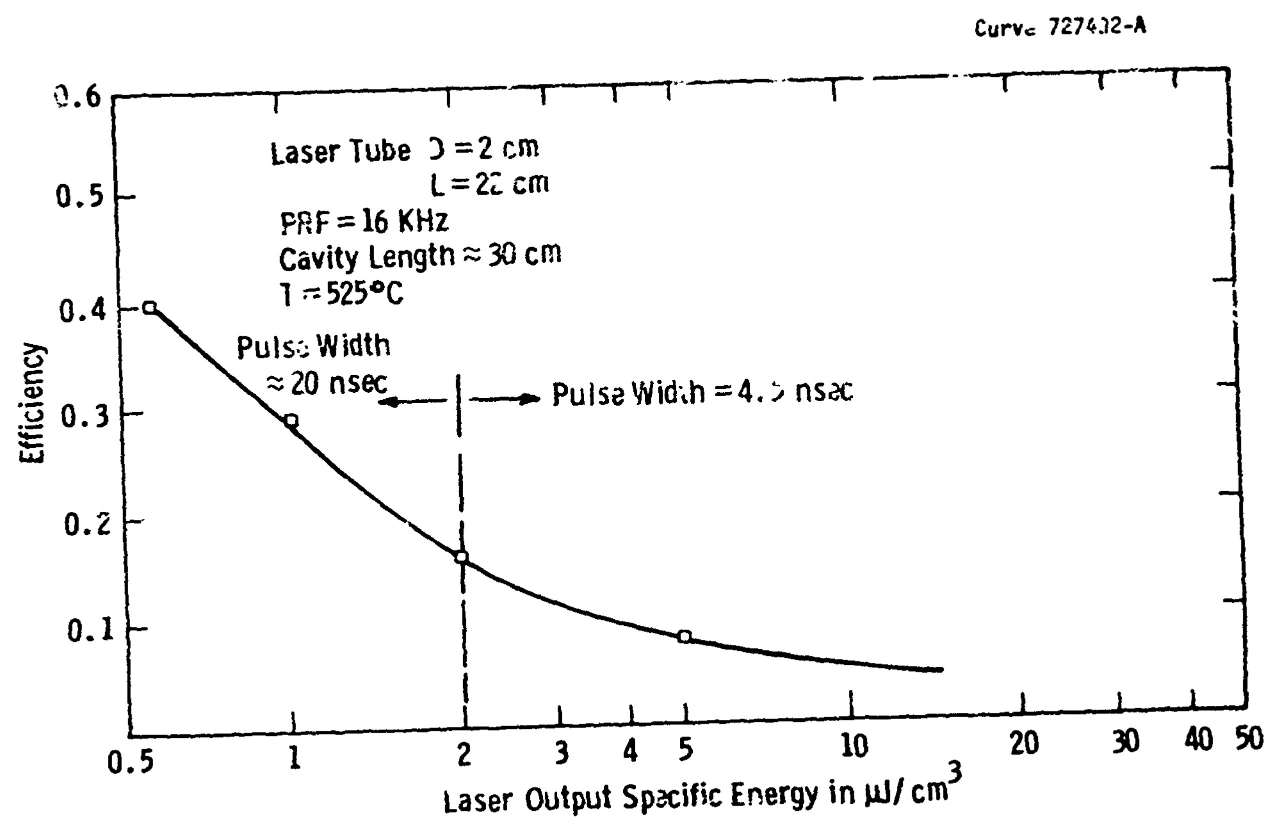

Fig. 4 — Laser conversion efficiency as a function of the specific output energy

3. CONCLUSIONS

A short resonator (30 cm) CuBr laser was built and its performance measured as a function of various operating conditions. Aside from packaging and prime power considerations which were not addressed in this study, the CuBr laser has exceeded all minimum specifications for the Navy bathymetry application. One set of simultaneously obtained

microJoules,

operating conditions are as follows: 140 μJ per pulse, 4.5 ns laser pulse width, 16 kHz repetition rate, 0.15% efficiency, 525°C operating temperature.

Our analysis indicates that in order to develop a Cu vapor laser for bathymetry application having an ultra-short laser pulse width (<5 nsec) the laser cavity has to be made shorter than or equal to 30 cm and the excitation rate has to be very high. Further issues relating to other bathymetry laser requirements such as energy per pulse, efficiency, repetition rate, lifetime, compactness, ruggedness and portability have been easily achieved by our existing laser tube.

We believe a CuBr laser can be built which will considerably exceed the performance obtained. For example, to increase the energy per pulse a MOPA configuration can be used. The efficiency can be increased by better power supply design such as matching the input impedance of the laser discharge with the output impedance of the pulser, and by increasing the current density and decreasing the current pulse width.

We are encouraged and optimistic about the CuBr laser performance. It seems to be that pure copper lasers are good for scaling up to high average power units but CuBr lasers tend naturally to be short pulse, high prf and long-lived lasers. We recommend that additional work be done to package a CuBr laser with existing performance into a practical system, and to demonstrate a CuBr laser with greatly improved performance.

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This report has been typed by Martha Fischer.